An Innovative Approach to Minimizing Bandwidth Usage for Mobile Military Database Synchronization

Matthew J. Zieniewicz, P. E.; Ron Szymanski; Thanh Nguyen
U. S. Army CECOM, Fort Monmouth N. J.

Background

The soldier on the modern battlefield needs to retrieve critical information in a timely manner while operating in a highly mobile environment. The information, above all, has to be timely and accurate for his needs. The soldier also cannot rely on a commercial communications infrastructure, so data networking features must be developed around existing military communications networks. There are several additional system requirements imposed on the soldier beyond that of any analogous commercial equivalent. These additional requirements are: security of the communications link, weight/power of the mobile station, ruggedness of the system, interoperability with legacy systems, ease of use, and visual organization. The combination of all of these conditions results in a unique system solution.

Until recently, technology was not at a sufficient maturity level to allow for battlefield information to be presented to front-line commanders in a timely fashion. Orders were transmitted over secure voice transmissions or data facsimile to lower echelon commanders. In limited areas or at higher echelons, custom battlefield management systems existed to transmit unique mission data around the battlefield to semi-portable ruggedized Unix computer systems.

With the emergence of future wearable computing platforms for the front-line soldier, digital information will now be able to be transmitted and received by units at the front-line of battle. These systems will allow the platoon leader to transmit digital pre-formatted messages, such as a call for fire (an artillery request), directly to rear area command and control software systems, which will then activate the appropriate military units to take action. These systems will also be able to receive digital operational orders from commanders at rear areas. Other unique features are envisioned, such as: still imagery capture, image transmission and retrieval, on-line help files and integrated mapping features. All of these features will be provided on a system that is ruggedized, secure and wearable, with interoperability with present rear area battlefield information systems and future distributed battlefield systems.

While proposed portable information systems provide a quantum leap forward in achieving the modern digital battlefield goals, they still fall short in database retrieval of critical information from rear areas. Some of these planned devices are also larger and heavier than desired for certain battlefield missions. For this reason, the Army is exploring both the means to retrieve database information over a wireless link in a timely fashion and the use of handheld devices as a means to process and display this information. Just as a mobile executive today can retrieve the day's critical business information, the soldier of the future on the battlefield will be able to retrieve critical information that will allow him to win the battle quicker and with less casualties for friendly forces.

The current problem

As previously stated, planned portable information systems fall short in the area of database retrieval and are also larger and heavier than desired for certain battlefield missions. The goal would then be to design a system that allows for database retrieval on a handheld

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
00 DEC 2004	**N/A**	**-**

4. TITLE AND SUBTITLE **An Innovative Approach to Minimizing Bandwidth Usage for Mobile Military Database Synchronization**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U. S. Army CECOM, Fort Monmouth N. J.**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM001736, Proceedings for the Army Science Conference (24th) Held on 29 November - 2 December 2005 in Orlando, Florida. , The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

computing device in a battlefield environment, leveraging commercial best practices and techniques wherever possible.

Four conditions make this problem unique for the soldier when compared to a commercial solution for the mobile executive and therefore the commercial world has not addressed aspects of this problem for the soldier. First, the soldier CANNOT dock his handheld at the end of the day and synchronize over a wired connection to a large remote database. For this reason, all his data communications must be through a wireless communications link with limited channel capacity. Second, the soldier must be fed information on a constant basis. He cannot be unaware of the enemy's actions or location for even a few minutes or he might be dead. For comparison purposes, updating information in the commercial world, while important, is not as critical. The commercial businessman might lose a sale due to his competitor's actions that day, but he may be able to recover that customer the following day or free up his time to concentrate his efforts on an even bigger sale somewhere else. Third, the soldier also must have a critical subset of information with him at all times. The soldier may be out of communications range for extended periods of time and cannot just wait until he "drives through the tunnel" or exits a "dead zone" in cell coverage. Therefore, he must have this subset of critical information with him at all times, along with an indication of the timeliness and accuracy of this information. Lastly, the soldier must be able to transmit and receive his information without it being compromised through eavesdropping techniques. It is not the same as in the commercial world and having your appointment calendar or credit card number stolen which can just be cancelled at the end of the day. Failure of the soldier's mobile information retrieval system in any of these areas could result in at a minimum with the soldier being unable to accomplish his mission and frequently result in more catastrophic consequences. The mobile soldier's system's inability to satisfactorily operate has similar consequences to medical device failures and can result in injury or death, definitely a serious business with serious consequences!

One Problem – Several Approaches

The goal of our research is to recommend a systems approach and architecture, based upon solid network engineering principles and mathematics, to retrieve battlefield current database information from a remote database over an intermittent wireless communications link to a handheld device. (Even with the recent advent of publish/subscribe methods, this research is still relevant to future information distribution schemes and can be extended and adopted with some modifications to a publish/subscribe methodology.) As part of this research, several approaches are being attempted with performance comparisons between each. This research will tackle the first three of the four hurdles to the system stated above. We will explore methods to do database retrievals and/or synchronizations with large remote databases over a wireless link. The impact of dead zones and periods of time without connectivity will be examined and a solution explored. A means by which critical information can be pre-cached on the user's device will be examined as one possible solution. All solutions will be accomplished within the size/weight/power restrictions of a handheld computing device. For this research, commercial data transmission protocols will be employed. The military has successfully adapted commercial communications standards in the past and added sufficient security methods to these techniques with success in the past. Therefore, our use of commercial protocols in our model accurately reflects a realistic implementation scheme for a possible fielded system. We do not anticipate a shift from the military use of commercial protocols in the future. Lastly, the security issue will not be addressed for one key reason. Security approaches are usually architecture specific and are very time/labor intensive to develop a new technique. To secure several different prototype systems, each with their own unique set of constraints, prior to the selection of the final product would be cost prohibitive and not the most judicious use of Government resources. For the

purposes of our research, adding the security implementation would not add value to the experiment, nor does omitting that portion invalidate our model and the validity of our results. Our goal is to focus on the information retrieval aspects of the problem within the constraints of a handheld wireless device, which may be operating out of communications range for critical periods of time.

On today's battlefield, some soldiers have a need to retrieve information from centralized remote databases that reside on secured commercial database platforms. There are several assumptions to the architecture for this system. These assumptions were used in the design of this experiment, since a tactical baseline needed to be approximated for realism and to allow for easy migration of the results to future 6.2 R&D programs. They will now be described in detail. One of the databases currently in common use for Army battlefield systems is Oracle. There is a trend underway to store future information on the battlefield in an XML-based schema and our new system should be flexible to adapt to this approach should it emerge. The interface at the server or back end is clearly defined and the processor at the server has reserve capacity to process local scripts or servlets. (These servlets will be used in the actual transmission of the data, as described later in this section.) Based on the large reserve processing capacity (service capacity) of the systems relative to the processing requiring for the servlets (inter-arrival times), it is not necessary for our experiment to include a modeling of the queueing system for the processing of the servlet at the database server. As information needs to be processed, it will occur in near real-time, with no perceptible lag of transmitted data WITHIN the server. It is assumed that the server will be in theater in a tactical environment and there will be access to this remote server to install any of these scripts or servlets. The servers will use a well-defined commercial operating system and these systems will have a consistent software configuration. Most of these systems run under versions of the Unix operating system or the latest version of Windows. For the receiving end of the information distribution system, we will employ a commercial handheld computing device as our hardware surrogate. There are currently no restrictions on this commercial handheld device; however, to ensure that the solution works under the most restrictive conditions, the handheld device will be a personal digital assistant (PDA), not a tablet computer. Since the PDA is more restrictive than a tablet computer, any system architecture can be scaled to the larger computing device without the likelihood of failure. The handheld device employed can use any choice of popular operating systems. Java, C++, Perl, Tcl/Tkl or other programming languages are permitted for handheld development, as long as they are supported for the operating system of choice. There are currently no restrictions on the display device for night-vision compatibility for the surrogate hardware used in this research prototype. The communications architecture must be able to be employed in a battlefield environment within a rapid timeframe. Therefore, some mix of existing or future tactical military radios utilizing the tactical Internet would be the most likely communications device for this system. The current battlefield communications architecture currently supports the transmission of data information over standard TCP/IP and UDP protocols.

After examining trade journals, product guides and researching commercial Internet sites, it was apparent that commercially available mobile database synchronization products were relatively new and none met all the criteria necessary for our end result. However, some approaches to the problem could be gleaned by adapting some of the techniques used in other synchronization methods. There are several database synchronization approaches to the general problem under examination. Full replication off-line could be attempted, but this is not a viable solution for two obvious reasons: data transmission time and limited storage capacity on the handheld device. Partial replication combined with some means of communications connectivity sensing has some limited merit, since the soldier will have information local on his device once retrieved. However, replicating even subsets of the data from a large database on a deterministic time interval basis wastes bandwidth by re-transmitting data that has not changed. (On the tactical battlefield, minimization of limited bandwidth has always been a challenge.) Ad-hoc

queries of the database as needed with no storage mechanism for the data on the handheld device, while simple to implement, is the not the most efficient, since channel capacity once again will be wasted on repeated retrievals for data that has not changed. After an initial review of numerous possible methods for an optimum approach, a push-pull of data based on time stamping, with pre-caching/caching of critical data on the handheld device, shows the most promise. This approach gains one the advantage of having critical data stored locally, as in the partial replication method, but alleviates the disadvantage of that method by NOT transmitting any data that has not changed. Under the system we propose, the complete subset of critical data is transmitted once, when the user enters the network. Afterwards, only changes to the data are transmitted out to each individual user. (This is analogous to the efficiencies gained by many video compression techniques, whereby only changes in pixels between frames are transmitted, not the entire frame.) The efficiency of this method is apparent when compared to simple ad-hoc queries with no caching. This push-pull method, utilizing caching, reduces the amount of data traffic transmitted, dependent on certain conditions. Work is in progress to determine the battlefield scenarios that result in a reduction in total cost for this transmission scheme. The traffic transmitted for queries without caching is illustrated in Figure 1.

$$\text{Unit Cost (UC)}_{IRT} = \sum_{N=1}^{\#\text{ of Mobile Record Entries (MRE)}} IT_n \quad \leftarrow \text{Equation } 1_{P-}$$

Over a mission timeframe, the equation becomes

$$\text{Equation } 2_{P-} \rightarrow \text{Total Cost}_{IRT} = \sum_{N=1}^{\#\text{ of IT's}} UC_n$$

IT_n = Information Transmittal (Request) per record entry in bytes

Figure 1.

When we cache information on the mobile client, the transmission equation (Z-Cache) becomes:

$$\text{Unit Cost (UC)}_{IRT} = \sum_{N=1}^{\#\text{ of Mobile Record Entries (MRE)}} IT_n - IC_n \leftarrow \text{Equation } 1_{P+}$$

Over a mission timeframe, the equation becomes

$$\text{Equation } 2_{P+} \rightarrow \text{Total Cost}_{IRT} = \underbrace{\sum_{N=1}^{\#\text{ of IT's}} UC_{IRTn}}_{\text{Equation } 1_{P+}} + \underbrace{\sum_{N=1}^{\#\text{ of MRE}} (PKV_n + PKN_n + TS_n + MID_n)}_{\text{Equation } 1^*_{P+}}$$

IT_n = Information Transmittal (Request) per record entry in bytes
IC_n = Information Cached on Mobile Client per record entry in bytes
PKV_n = Primary Key Value in bytes
PKN_n = Primary Key Name in bytes
TS_n = Time Stamp in bytes
MID_n = Mobile Client ID in bytes

Figure 2 – Z-Cache.

For long mission profiles, efficiencies through pre-caching, become apparent in the Z-cache equation above.

Conditions Ideal for Optimization of Bandwidth Utilizing the Z-Cache Method

In general, it is optimum for long mission times, relative to the update interval, where a significant number of the individual records (entities) have no change in their data and thus are not re-transmitted. There are two factors that affect the relative efficiency of this method. The first factor is the mission length versus the desired data refresh rate for the mobile device. For long mission lengths versus update intervals, the efficiencies are greatest. Since most update intervals are projected to be three minutes or even less and mission times typically vary from six to seventy-two hours, this condition is achieved. The second factor is the update interval versues the number of changed database records. This ratio will vary widely based on operational and needs to be analyzed further as part of this research through experimental data. Since this system would typically be employed in an infantry scenario, one of the key pieces of information transmitted to each soldier would be the relative position of current friendly and enemy units. During relatively static conditions, the network traffic load would be minimal under this approach. (The ad-hoc query method or either of the replication methods would be generating more data traffic under these conditions in comparison.) As the battle progressed, the pre-cache system would start to load the network based on the number of unit movements. It is predicted that these movements would still result in less traffic than the other more traditional data retrieval and synchronization methods described earlier. To determine the actual efficiencies gained by this approach under varying conditions, we decided to perform limited test runs by implementing an actual surrogate system with complete hardware and software. The advantage to this approach is that it also proves the feasibility of a relatively easy transition of the method to future fielded mobile computing systems. The disadvantage is the additional time and labor and the limited data sets from experimental runs versus a simulation-based approach. (More details and analysis on this data will be available at the conference.)

Experiment Design – Testing of the Z-Cache Method

For our approach to the problem, we decided on the following configuration for our experiment design (See Figure 3.) To emulate the remote database server, a Windows 2000 server machine was established with an Oracle database, along with Java 2 Enterprise Edition software, was configured for our external data connection. For our database schema, we employed a subset of the information fields used under the Mobile Command and Control system (MC2), a by-product of the Agile Commander Advanced Technology Demonstration and the DAVINCI architecture. (Initially, we had planned on using the Joint Common DataBase (JCDB), but its use at lower echelons targeted for our mobile system is limited.) We employed a Java servlet to perform several functions. It allowed us to communicate with the Oracle database. It performed our time stamp comparisons of the server data versus the handheld data. Finally, it transmitted the data out over a port to the wireless LAN. For the handheld device, we chose a wireless Compaq iPaq for the convenience of its PCMCIA expansion slot feature and wide support for the Pocket PC. We installed Oracle 9iLite to allow for remote subsets of our master database to be stored locally on the Compaq iPaq using the expansion cards. For testing purposes, we are using a commercial wireless LAN network to transmit our data from the central server to a wireless handheld using the 802.11 protocol. (Prototypes of future military radios were to be employed initially, but the limited availability of these devices precluded their use.) Though the transmission rate achieved under these laboratory conditions is higher than what will be typical on the battlefield, our data-gathering equipment is focused on the actual bytes transmitted and thus the high data rate is immaterial. We are using a LAN analyzer to actually capture the total numbers of bytes transmitted, as well as the peak burst rates for unit time, which

will give us an accurate indication of the bytes transmitted. Using a wireless LAN allows us to simulate intermittent connectivity, by selecting physical locations within our lab environment where the wireless connection is lost. Static information will be pre-stored. Information will be pushed to the client using a Java servlet. A Java application will communicate with this servlet to retrieve information.

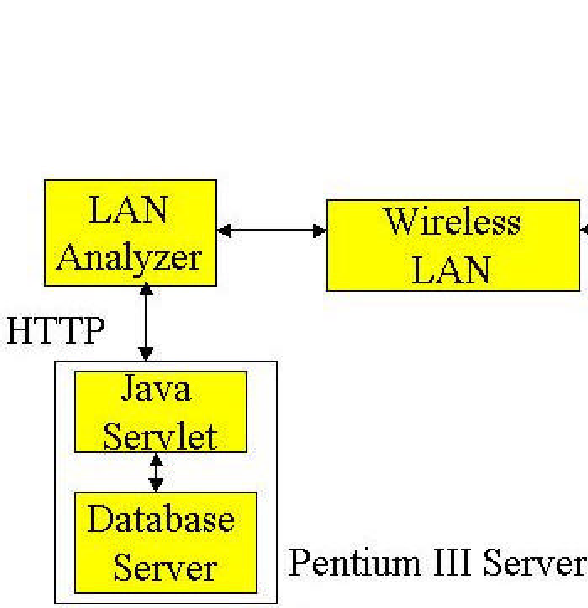

Figure 3

The Compaq iPaq has some advantages in small size and footprint, but these are traded off against implemented features. In order to implement this push-pull scheme, we will extract timestamp information from the database tables.

During the testing phase, wireless packets will be captured to determine the actual traffic load on the communications channel for each scheme proposed. This will include any query comparisons to system tables for timestamp information, not just the actual battlefield data retrievals. The load on the communications channel will be a key factor in the final system selection since channel capacities are limited on the modern battlefield. Storage and memory footprints on the handheld device as well as processing requirements will also be key elements in the final evaluation.

.

Further Research, Recommendations, and Transition of the Results

At the time of the initiation of this project, the primary means of information storage and retrieval on the battlefield was through databases. Now, with the emergence of publish/subscribe systems, there is a mix of both database and publish/subscribe technologies on the battlefield. Time will tell which technology or the appropriate mix of technologies that will be used. Determination of that mix is not the focus of this research and beyond the scope of this paper. As the Army defines its XML namespaces more thoroughly, we can do additional testing for data transmission efficiencies based on actual XML implementations.

It may be possible to adapt the methods and solution suggested as part of this research, with some modifications, to the publish/subscribe information distribution problem. By the same

token, this research may be adaptable to analyze and model both the Force XXI Battle Command Brigade and Below (FBCB2) system, as well as the Command Post of the Future (CPOF) system, but further engineering data needs to be analyzed on these systems before an extension of this technique to their respective systems can be guaranteed.

An interesting modeling problem for further examination would be to compare the bandwidth efficiencies of the push-pull Z-cache system described with a traditional publish/subscribe system for network loading under typical battlefield conditions. This could be done through simulation runs, modeling both the Z-cache system with proposed publish/subscribe methods to be potentially used on future Army command and control systems. Due to time constraints and limited availability of resources, test runs using the experimental design were chosen as the testing methodology over simulation runs. For thoroughness, both actual data from a surrogate system and numerous simulation runs with an accurate model of the proposed system should be performed. Each testing approach has its own merit. The surrogate system proves the relative of the new method and architecture to be transitioned and implemented in future fielded systems. Modeling and simulation will determine the optimal operational scenarios under which the new system would achieve bandwidth efficiencies vice other approaches, such as traditional publish/subscribe methods. Also, the research here analyzed the efficiencies of this new approach without background network traffic. Simulation runs including background traffic would better illustrate the net gains in efficiencies from this method.

The Army is migrating to a modern digital battlefield. As commanders use lightweight handheld data devices for their day-to-day work when not at war, they will come to expect the same information flow on the battlefield. This project explores several means to accomplish this with surrogate battlefield systems under controlled conditions and will provide the valuable groundwork to fielding a portable data device capable of secure wireless database retrievals under battlefield conditions.